High Momentum GEM RICH Parameterization

Based on SBU/BNL 2015 Test beam detector

Henry Klest

Stony Brook University

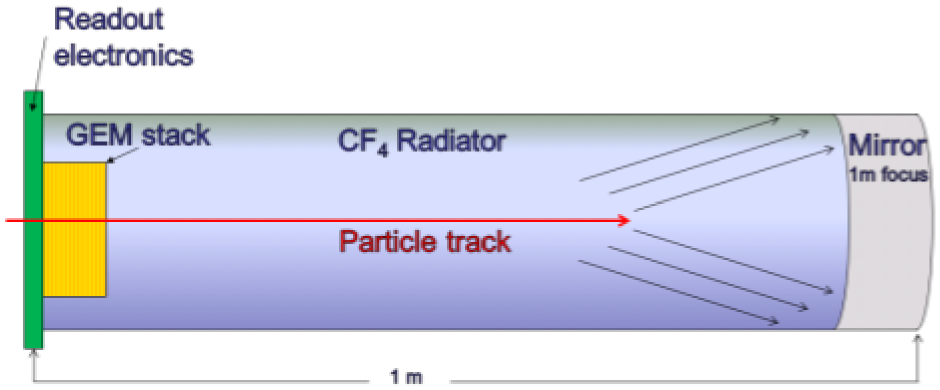
Disclaimer: I’m a Ph.D student who is neither a coding expert nor a RICH expert, so please feel free to interject if I say something incorrectly, and excuse the PowerPoint acrobatics to make up for my poor ROOT skills

Introduction

- Goal is to produce a parameterization validated through comparison with test beam and the results of other groups
- Comparison with dRICH gas portion simulations is especially helpful
  - ~ One month of work not enough to include all the effects included in dRICH sims, some values (such as magnetic field effect on resolution) stolen to get quicker results
- Using the parameterization, we can characterize how the GEM RICH will perform under variation of other parameters (gas, readout, tracking characteristics, pixelation, pressure, optical transparencies, etc.)

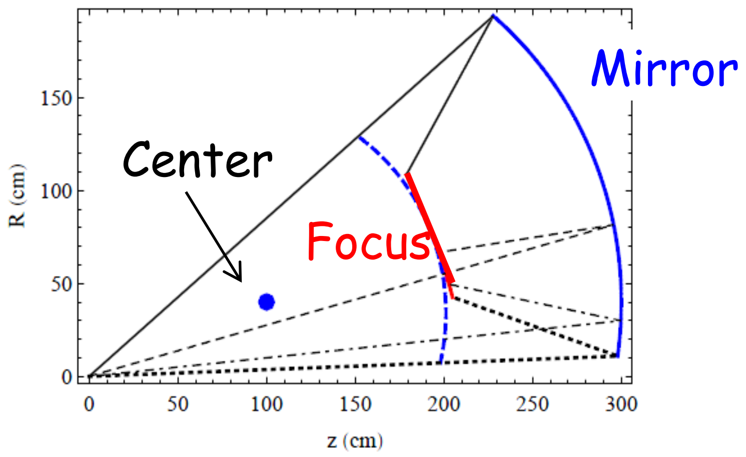
https://arxiv.org/pdf/1501.03530.pdf

Setup



- Same physical setup as described at Temple by P. Garg
- 1m of CF4 radiator at 1.003 bar (slightly overpressure)
- Particles perpendicularly incident on spherical mirror, focused onto a GEM stack directly in beam path
- Quintuple GEM readout, no need for magnetic shielding, GEMs proven to work in high-B environments
- Two test beams, one at SLAC and one at Fermilab, provide realistic conditions that should be in agreeance with a correct parameterization.

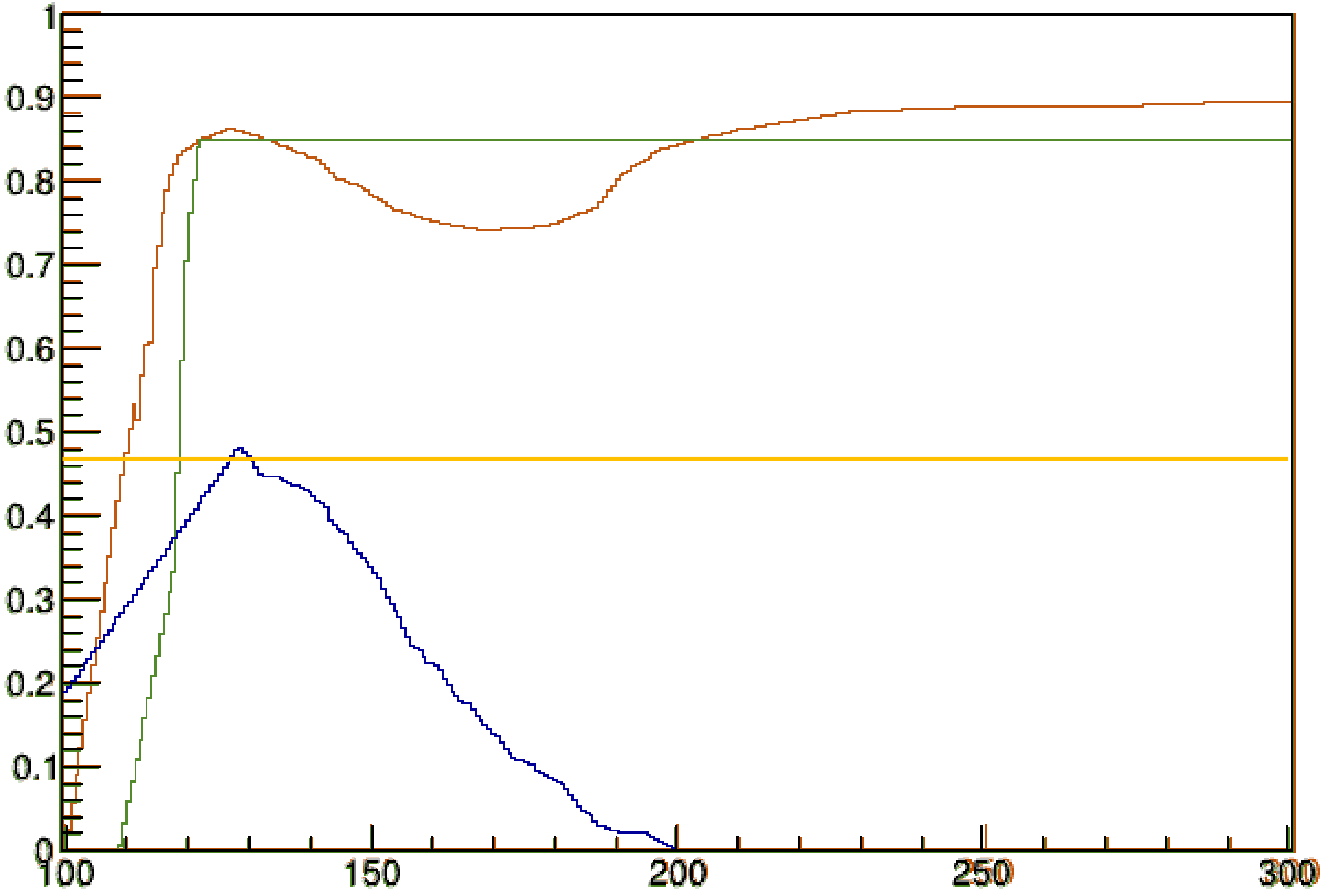
RICH Optics



Parameterization - CRK

- Generate photons according to Cherenkov spectrum
- Efficiencies provide detected Npe
  - Many efficiencies are functions of wavelength
- Smears degrade Cherenkov angle resolution
- Modular framework designed to allow for mixing and matching of gases, photodetectors, pressures, etc.
- Pi, Ka, Pr, and e all included
- Once cleaned up, will be available in the PID GitLab

Efficiencies



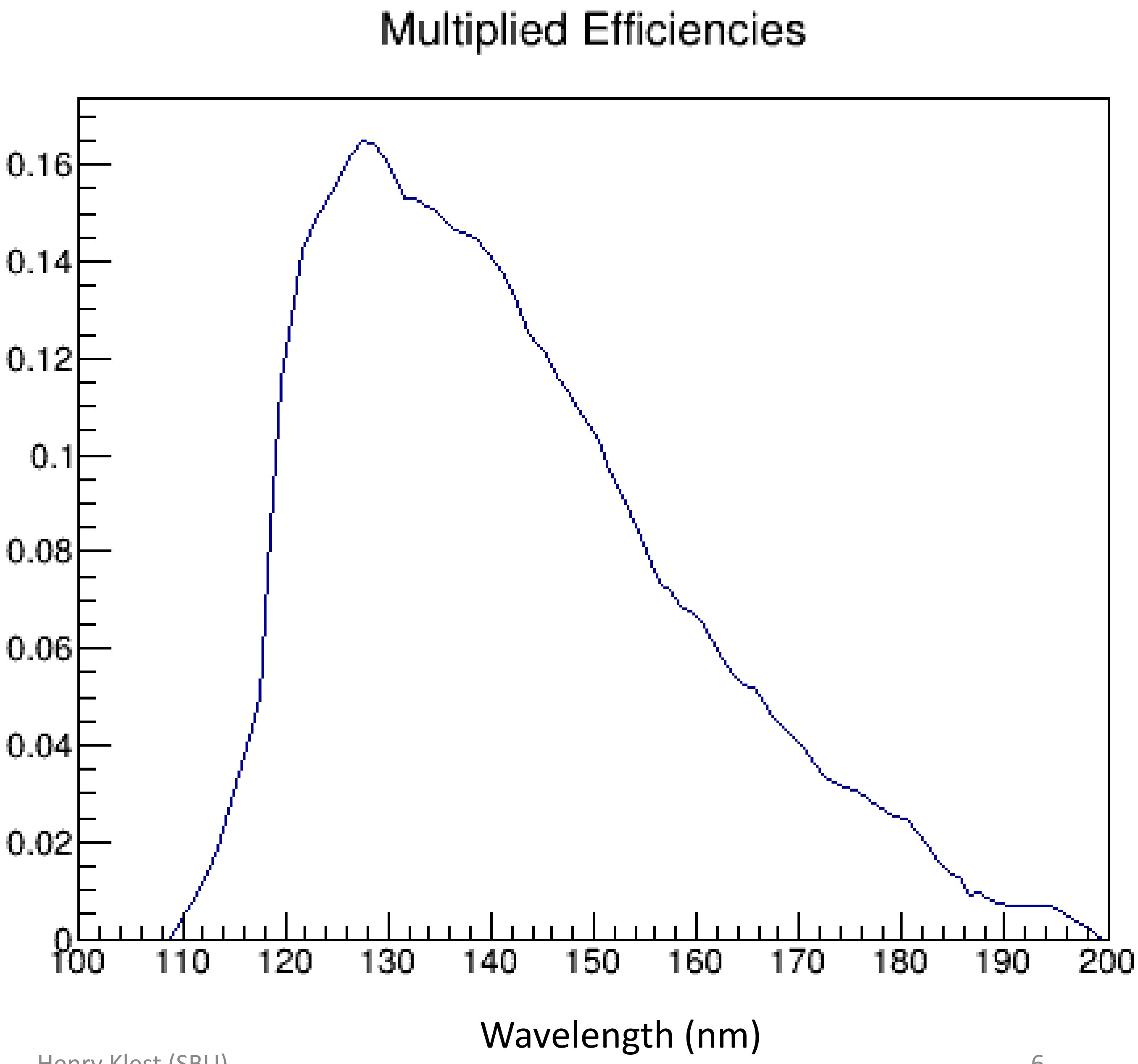
Green: CF4 Opacity

Orange: Mirror Reflectivity

Blue: CsI Photocathode Quantum Efficiency

Yellow: All Lambda Independent Efficiencies

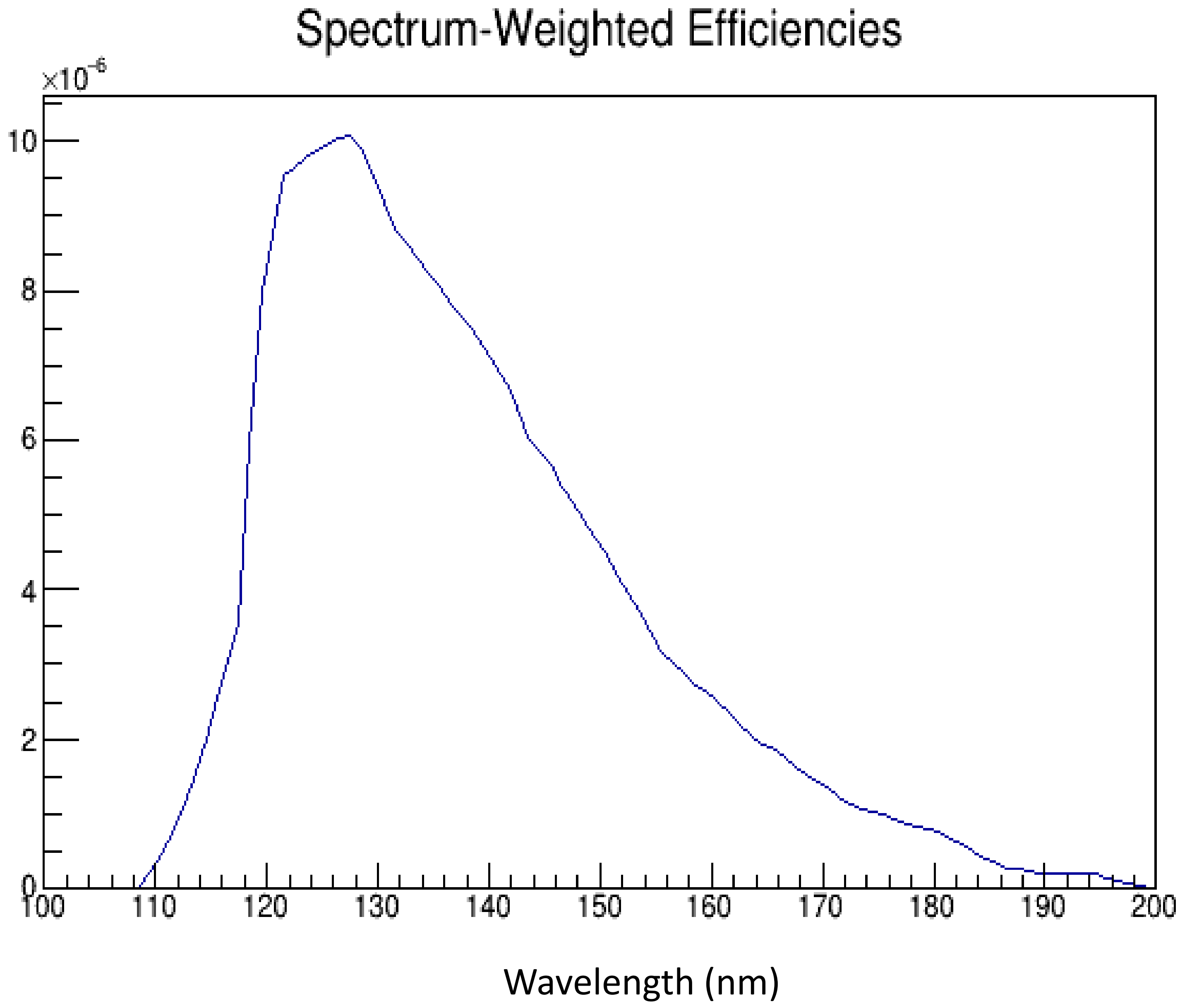
- Included:
  - Mirror Reflectivity
  - CsI QE
  - GEM holes
  - Mesh transparency
  - CF4 opacity
  - GEM Collection Efficiency
  - Single Photon Detection
- ~17 Npe calculated at β=1
- Peaked nature of total efficiency provides defense against chromaticity issues near Sellmeier pole



"Go where the light is"

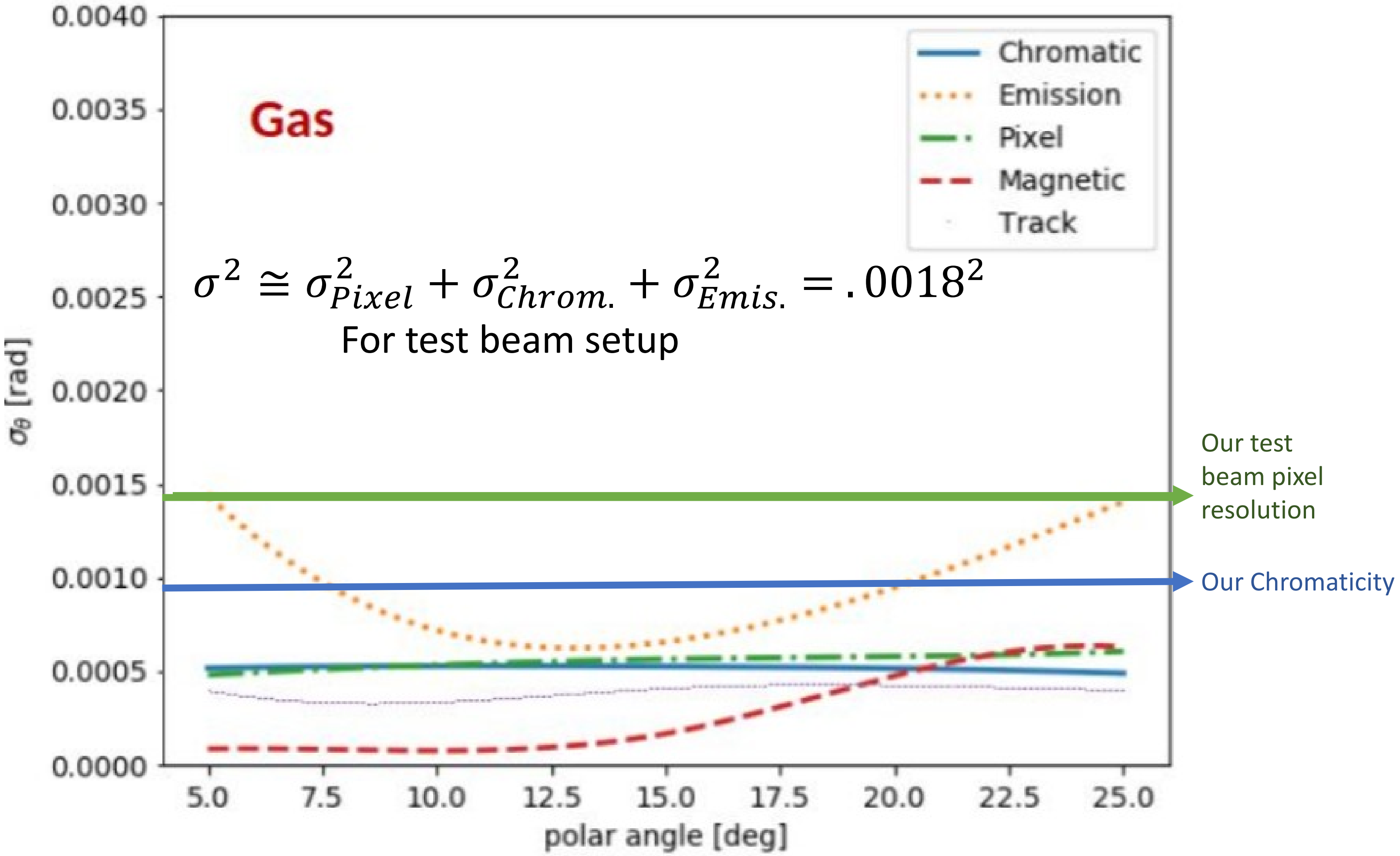
Compared to a PMT, CsI active at much lower wavelengths

Multiplying the overall efficiency by $\frac{1}{\lambda^2}$ shifts the distribution further left and illustrates the relative importance of lower wavelengths. But what about chromaticity?



Gaseous portion of GEM RICH and dRICH are largely similar, differences in readout (GEM vs PMT), length (100 cm vs 160 cm), and gas choice (CF_4 vs C_2F_6). Haven't yet implemented polar angle. Comparing to their (much more mature and detailed) resolutions as a sanity check:

Comparison to dRICH resolutions

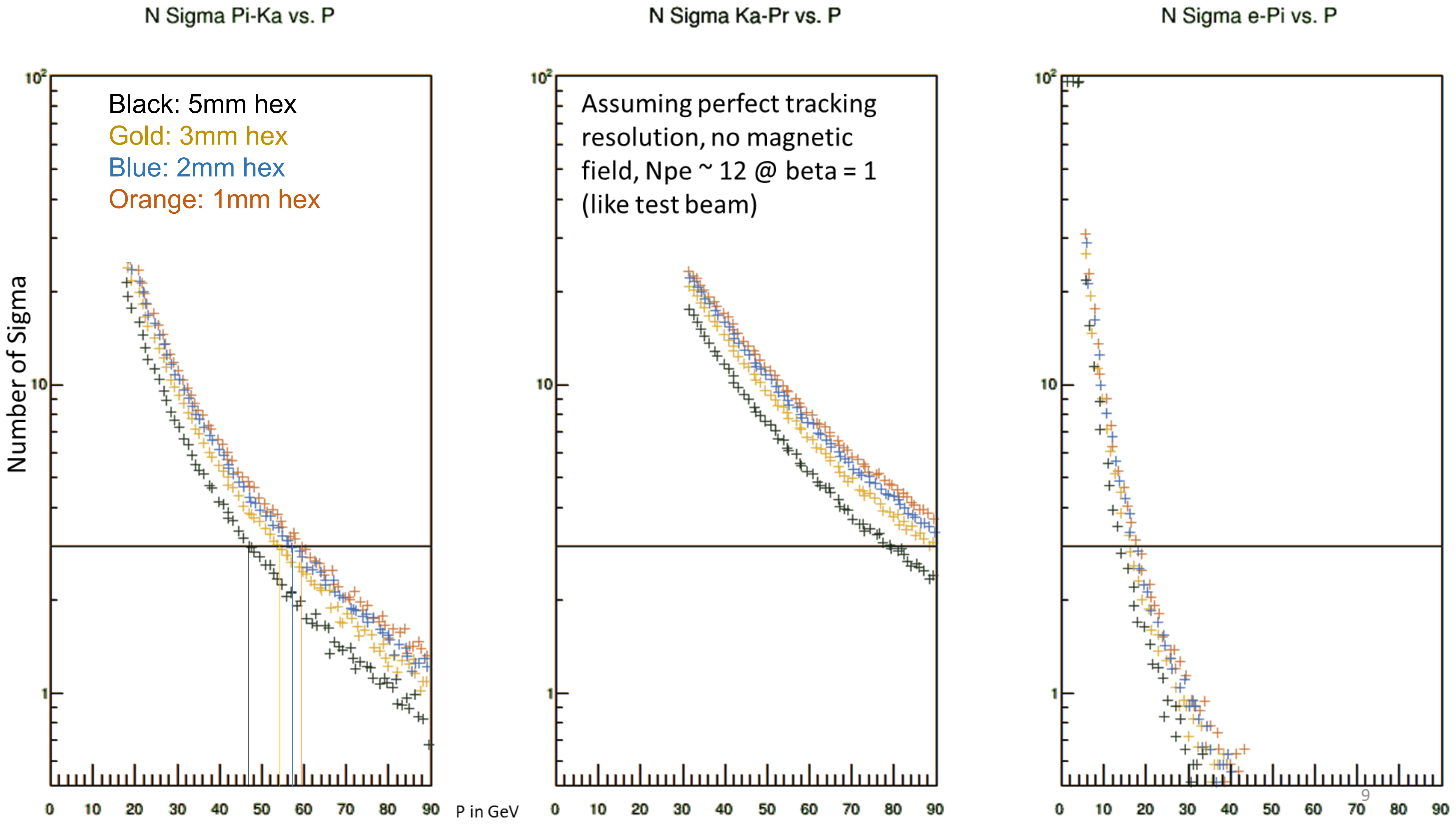


Chromaticity and wavelength dependence of efficiencies included by design in our parameterization,
Chromatic $\sigma_\theta = .00092$

Pixel resolution is padsize/$\sqrt{12}$
Assuming a no-charge-sharing pad arrangement, test beam used 5mm ($\sigma_\theta = .00144$) hexagons with intention to go smaller

Emission term sub-leading in our geometry (shorter radiator, no off-axis focusing)
Using conservative estimate of σ_θ =.0006

Test beam tracking resolution was excellent, effect on σ_θ is negligible in quadrature (will vary later)

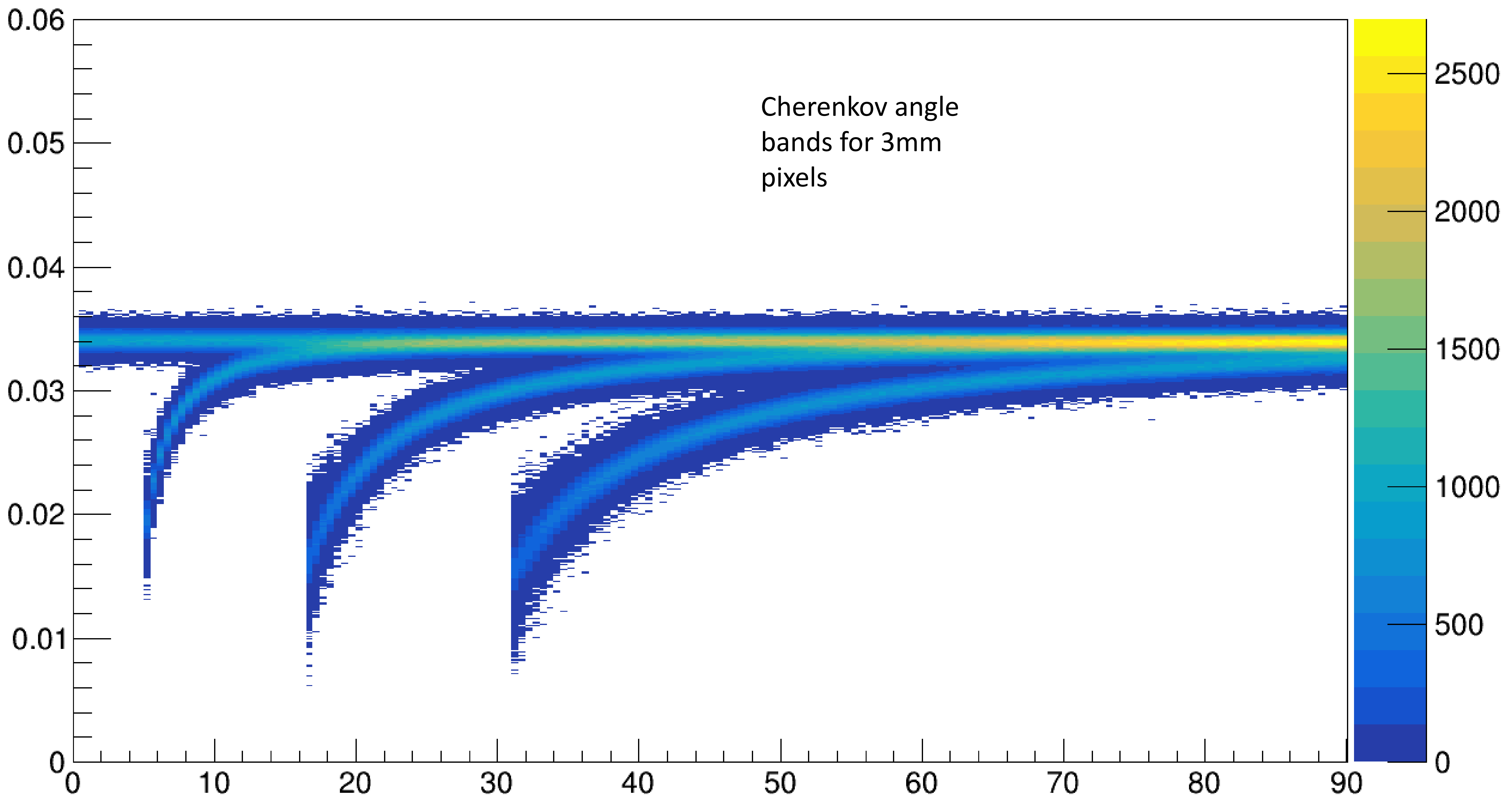

N Sigma Pi-Ka vs. P
N Sigma Ka-Pr vs. P
N Sigma e-Pi vs. P
Black: 5mm hex
Gold: 3mm hex
Blue: 2mm hex
Orange: 1mm hex
Assuming perfect tracking resolution, no magnetic field, Npe ~ 12 @ beta = 1 (like test beam)
Number of Sigma
10^2
10
1
0 10 20 30 40 50 60 70 80 90
P in GeV

Pixel Resolution Summary Table

Hex Pixel Size (θ_c Resolution)	Pi-K 3 sigma threshold (GeV)	K-Pr 3 sigma threshold (GeV)	e-Pi 3 sigma threshold (GeV)
5mm (.00144)	47	80	15
3mm (.000866)	52	90	18
2mm (.000577)	57	95	19
1mm (.000289)	60	98	19

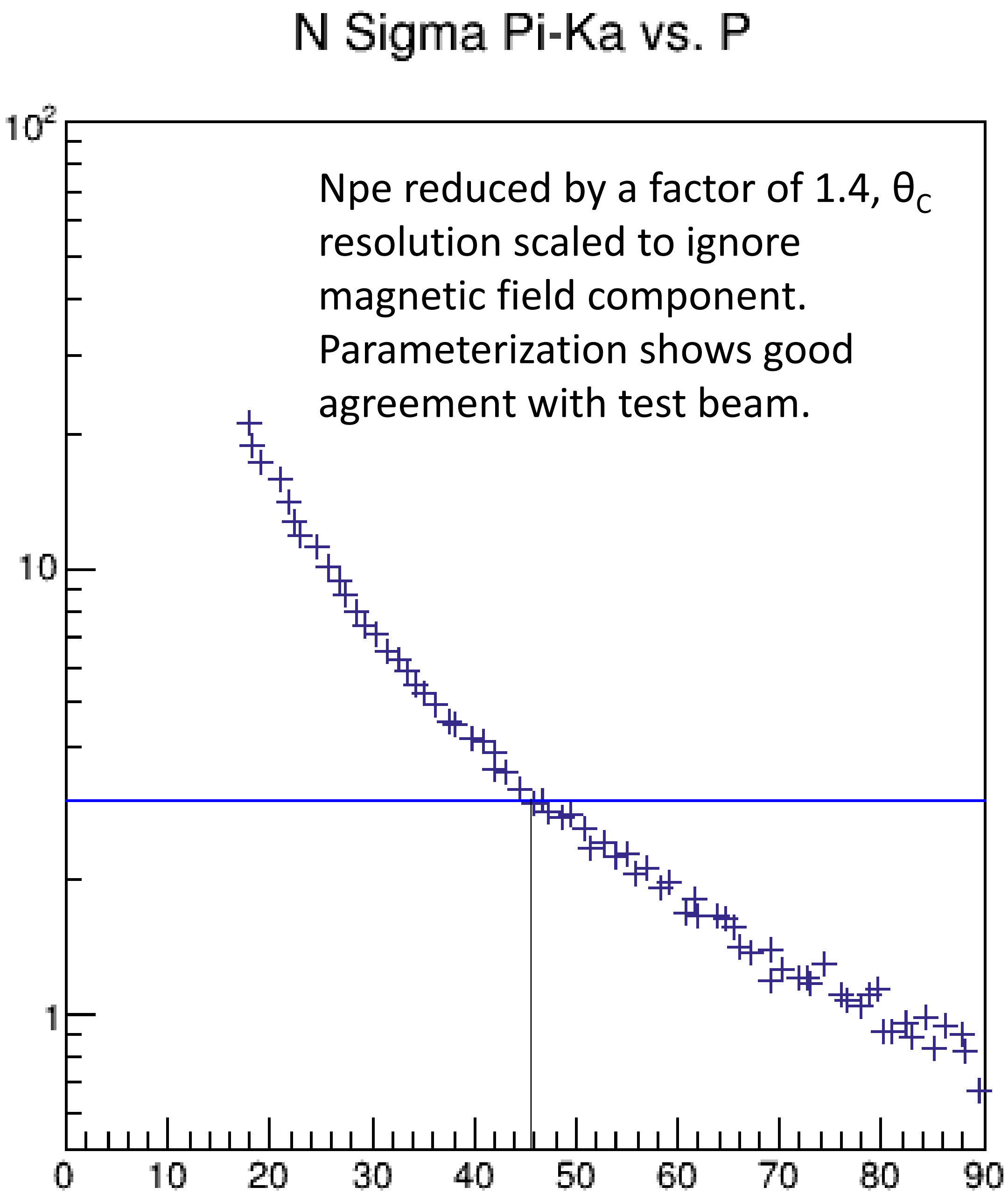
Need to determine cheapest ways to decrease resolution, no use in spending twice as much money on reducing pad sizes if another resolution is already dominant. Note in this case that magnetic, tracking resolutions are neglected.

ThetaC vs. P

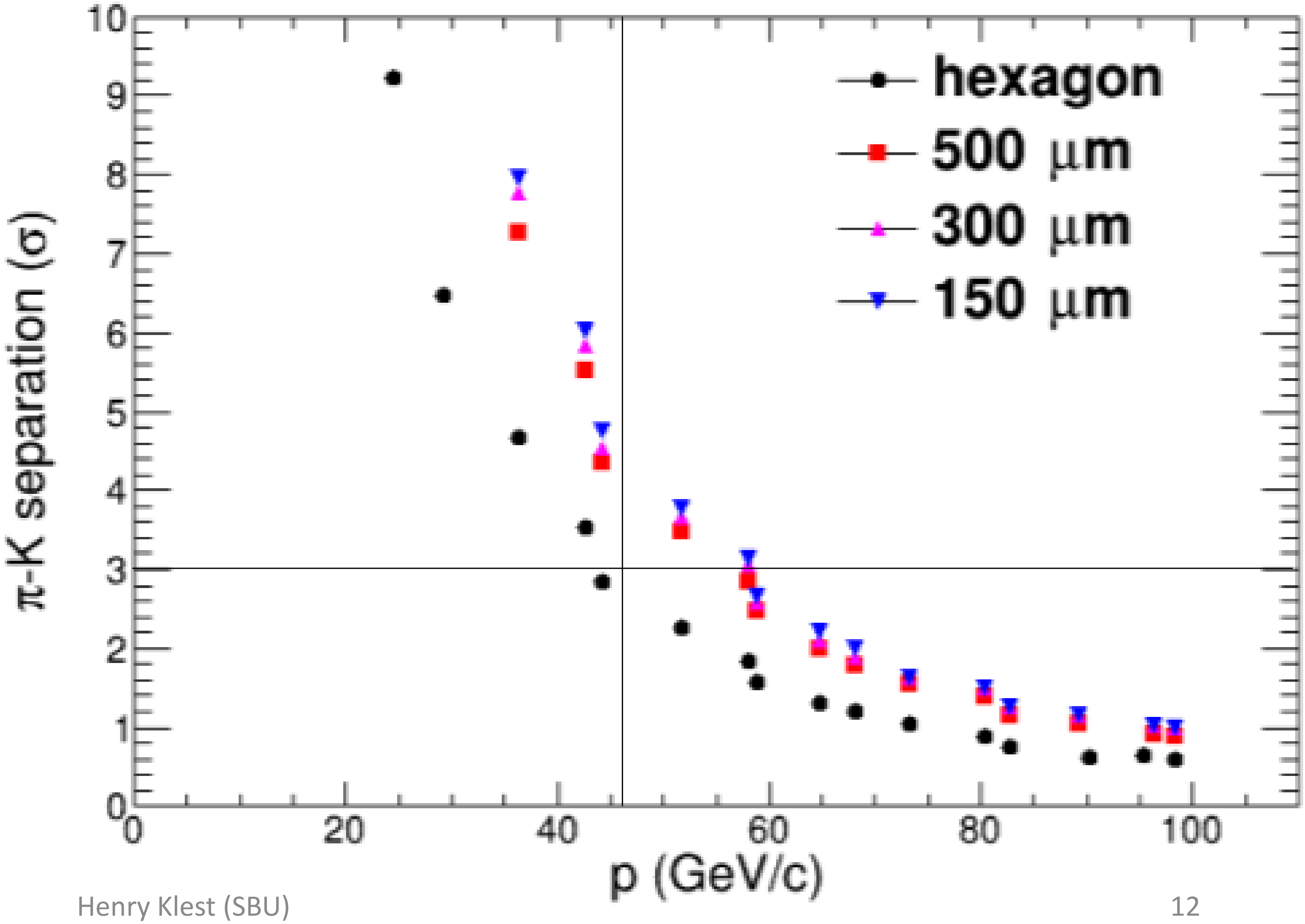


Cherenkov angle
bands for 3mm
pixels
0.06
0.05
0.04
0.03
0.02
0.01
0
0
10
20
30
40
50
60
70
80
90
2500
2000
1500
1000
500
0

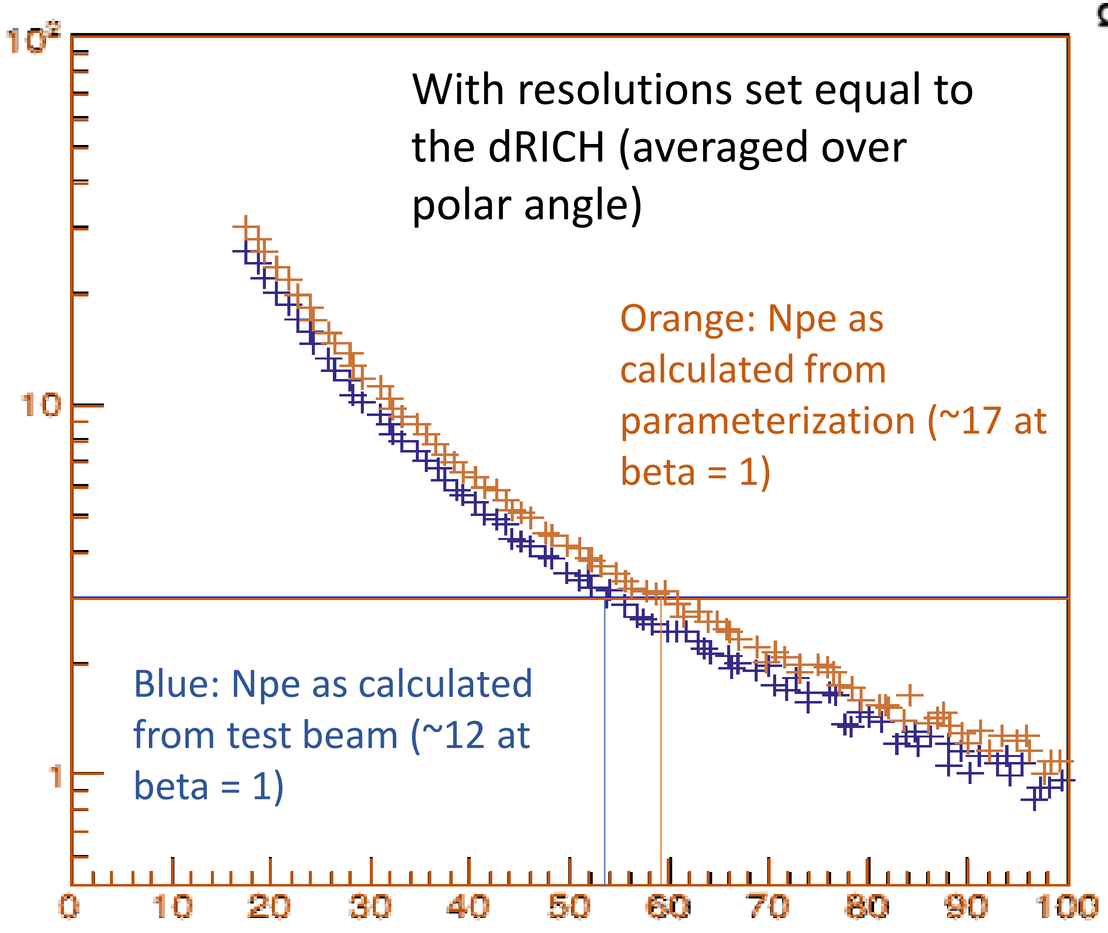
Checking parameterization vs. test beam results…

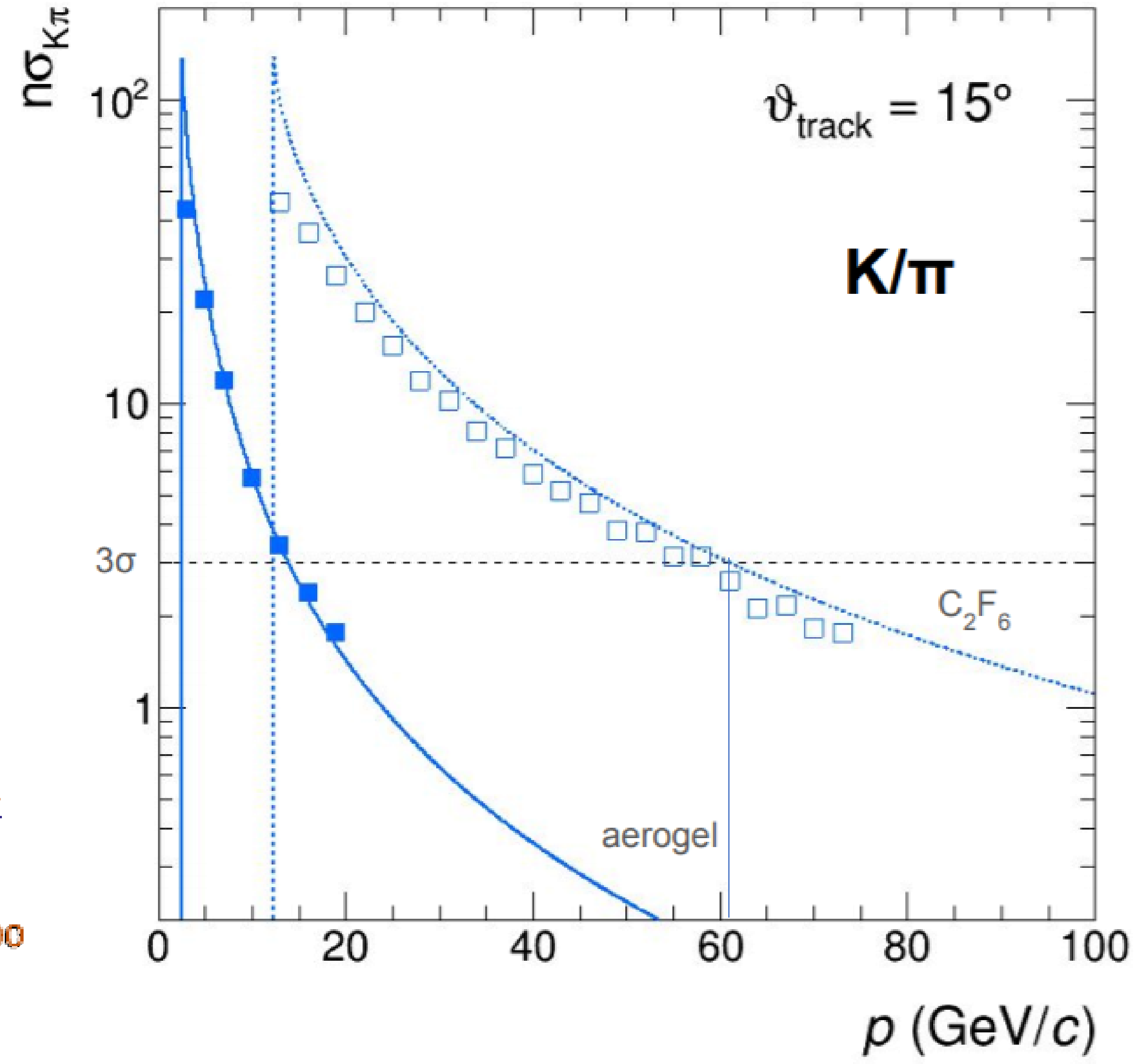


Test beam results



Checking parameterization vs. dRICH results, 3 sigma threshold slightly lower, but close. Possibly due to shorter radiator, less Npe from CF4.

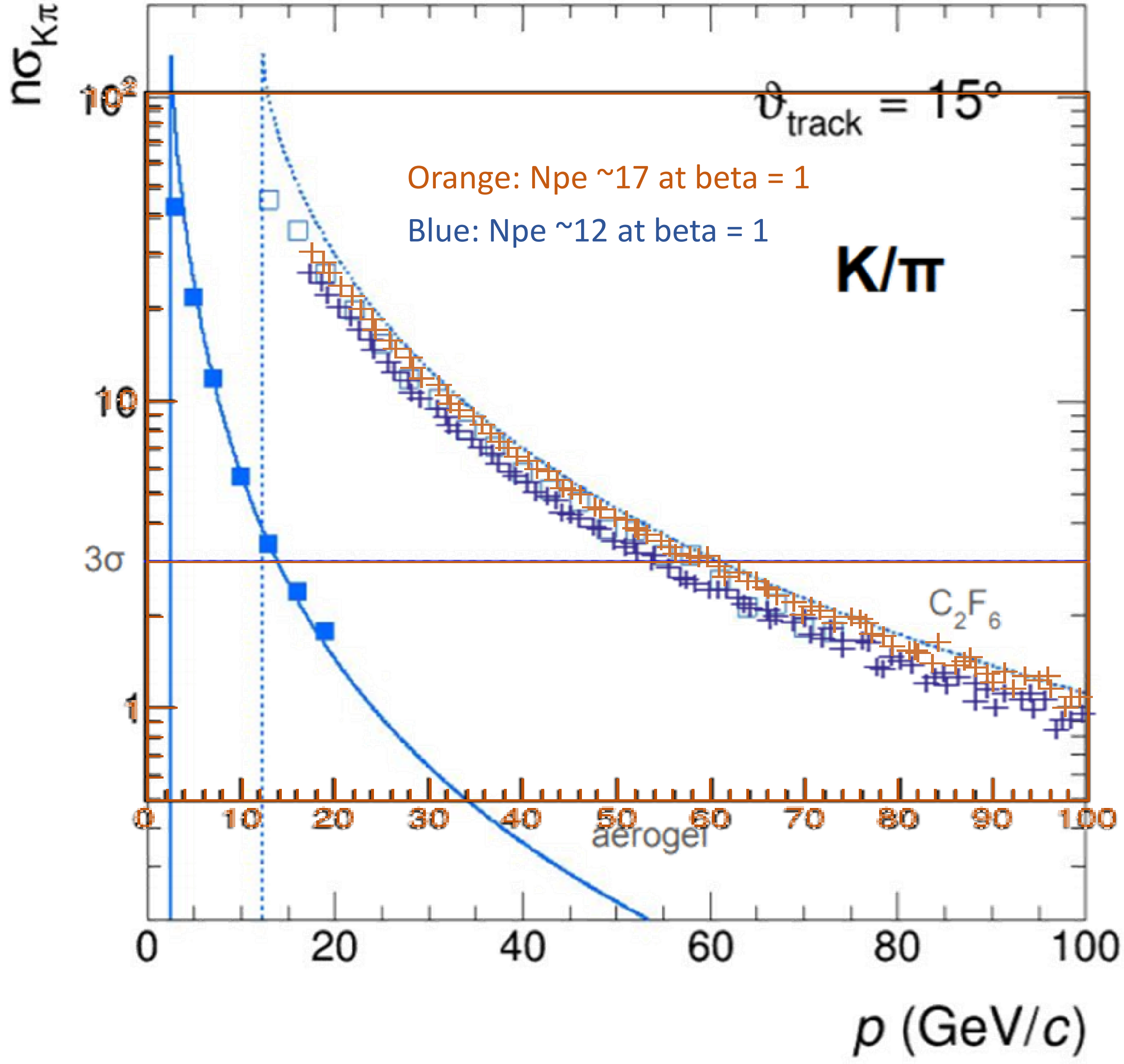


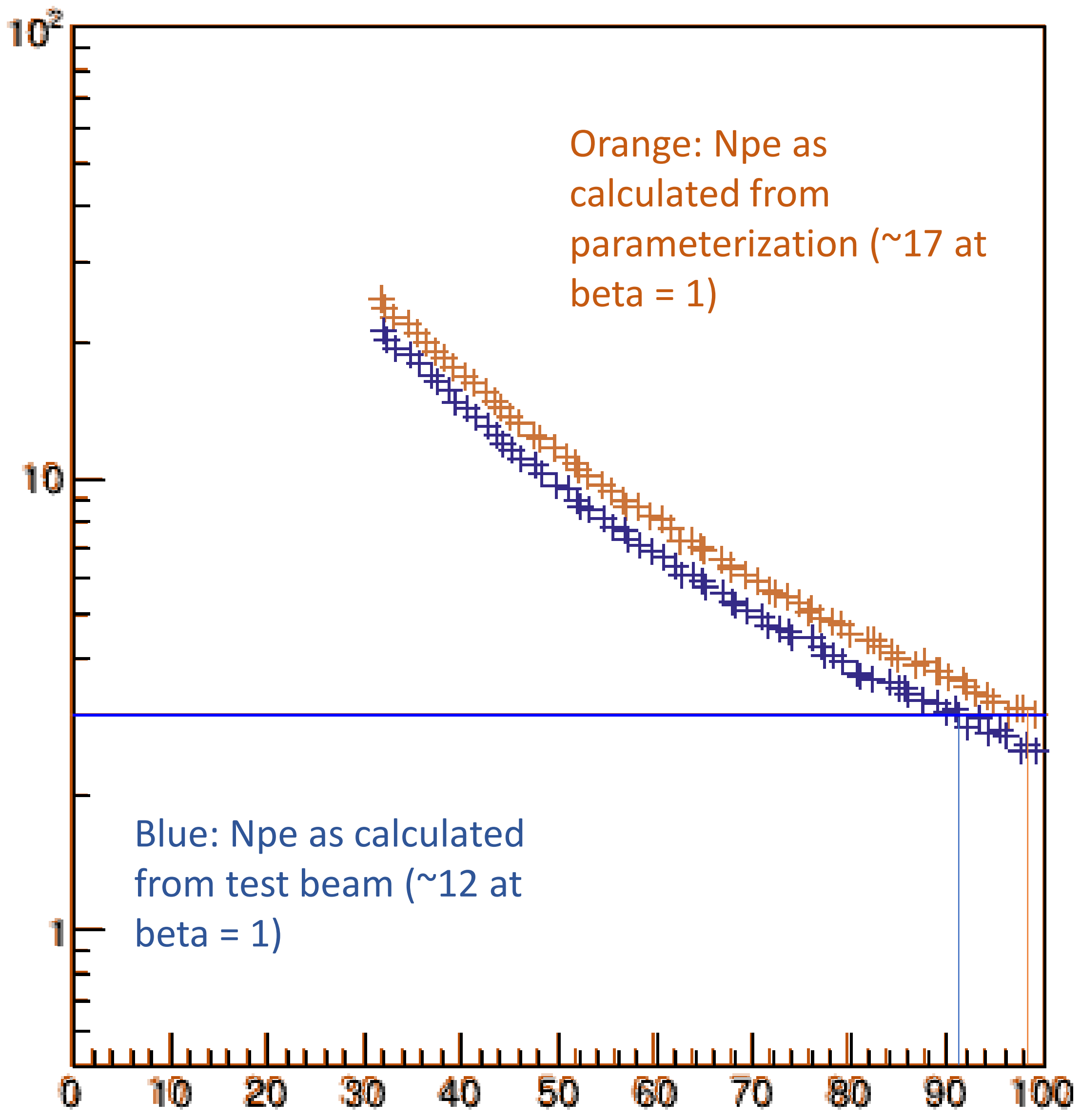


All resolutions except for chromaticity are the same, overlay as a sanity check.

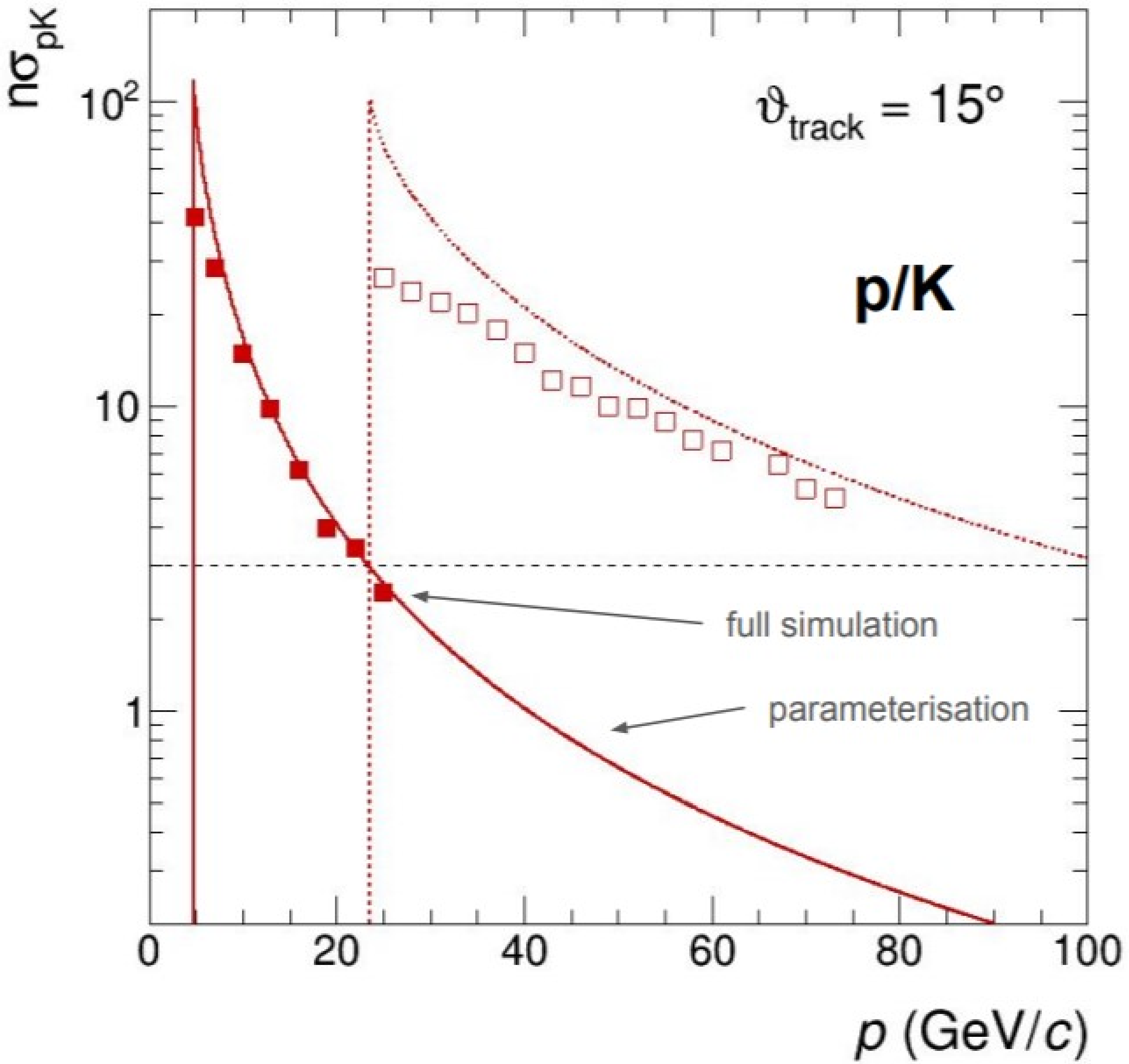
Overlay illustrates broader momentum coverage of dRICH due to C2F6 having lower Cherenkov thresholds

Overall very good agreement!

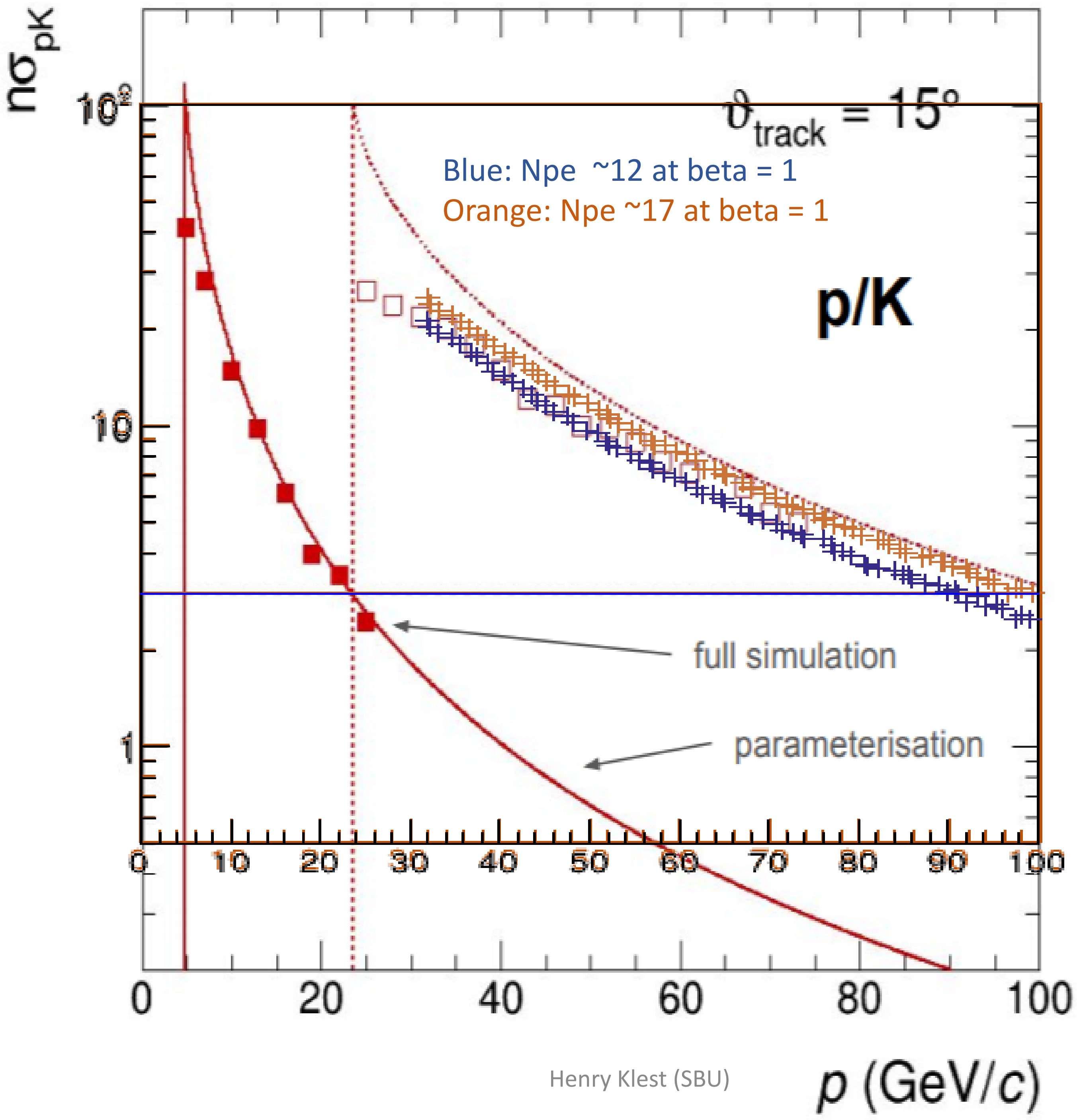




Orange: Npe as calculated from parameterization (~17 at beta = 1)
Blue: Npe as calculated from test beam (~12 at beta = 1)
10^2
10
1
0 10 20 30 40 50 60 70 80 90 100

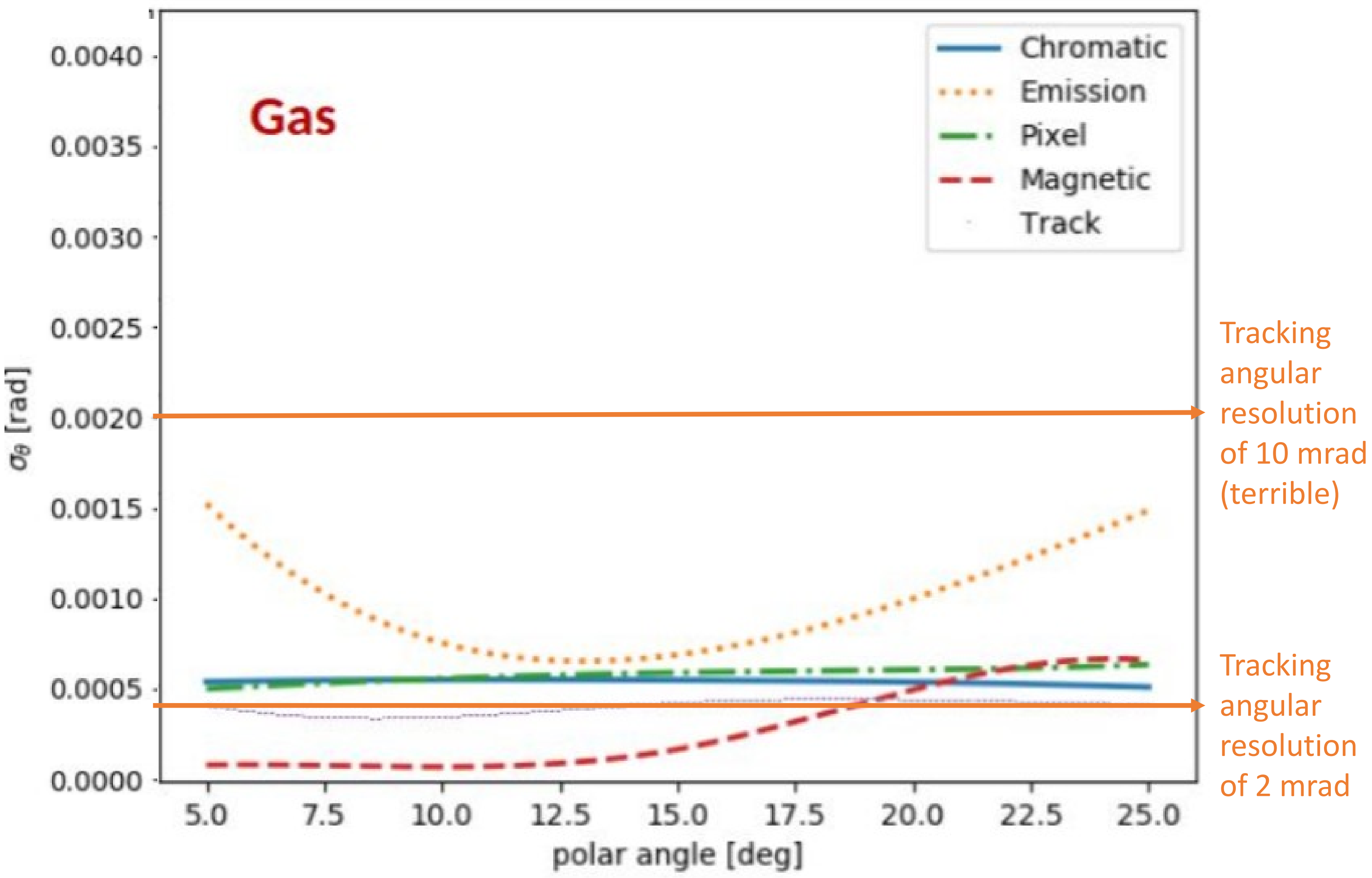


$n\sigma_{pK}$
$\vartheta_{track} = 15°$
p/K
full simulation
parameterisation
10^2
10
1
0 20 40 60 80 100
p (GeV/c)



$n\sigma_{pK}$
$\vartheta_{track} = 15°$
Blue: Npe ~12 at beta = 1
Orange: Npe ~17 at beta = 1
p/K
full simulation
parameterisation
p (GeV/c)

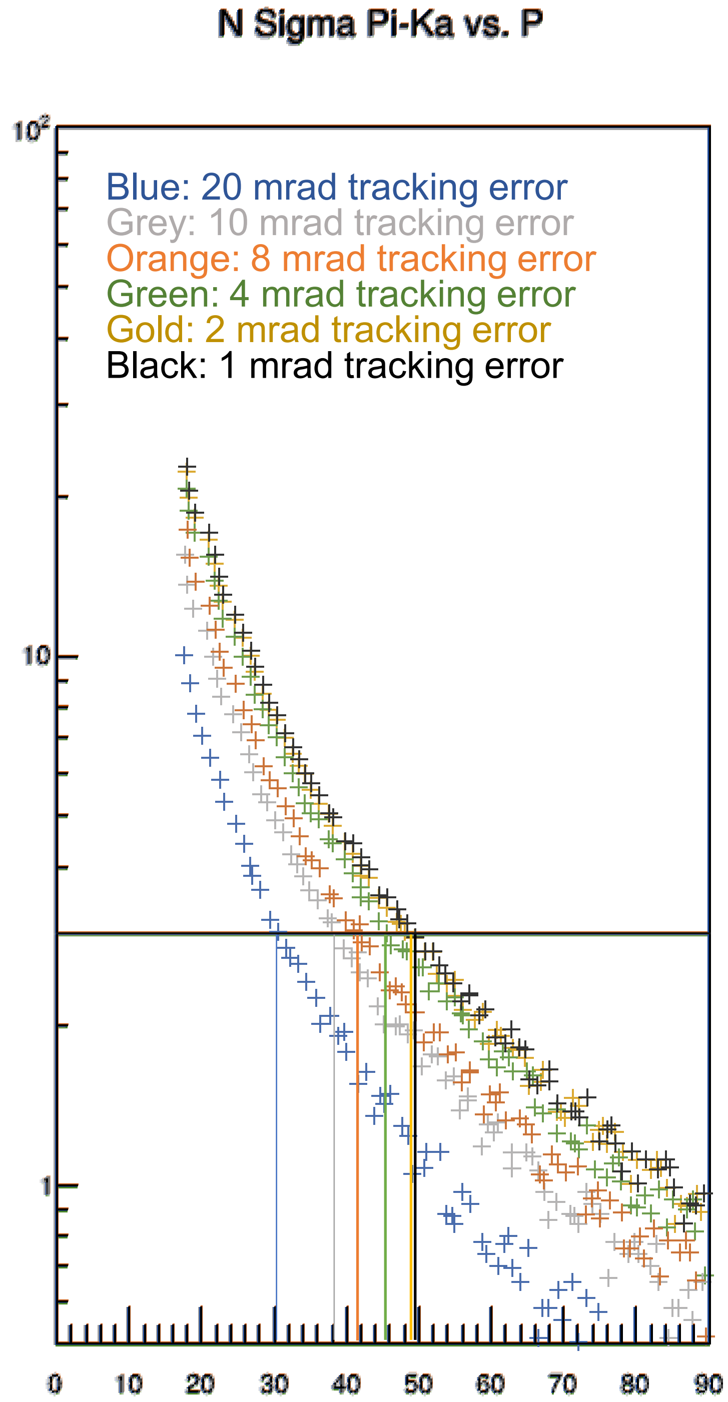
Tracking error

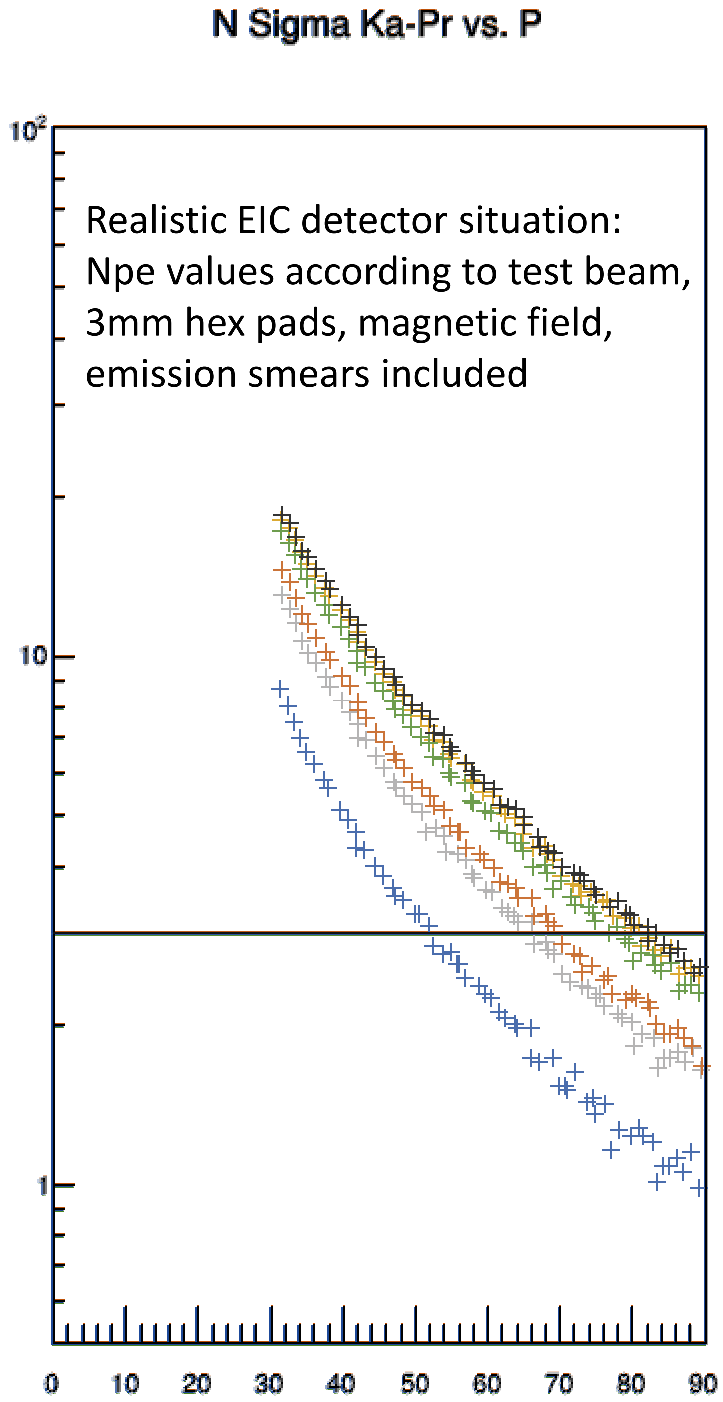


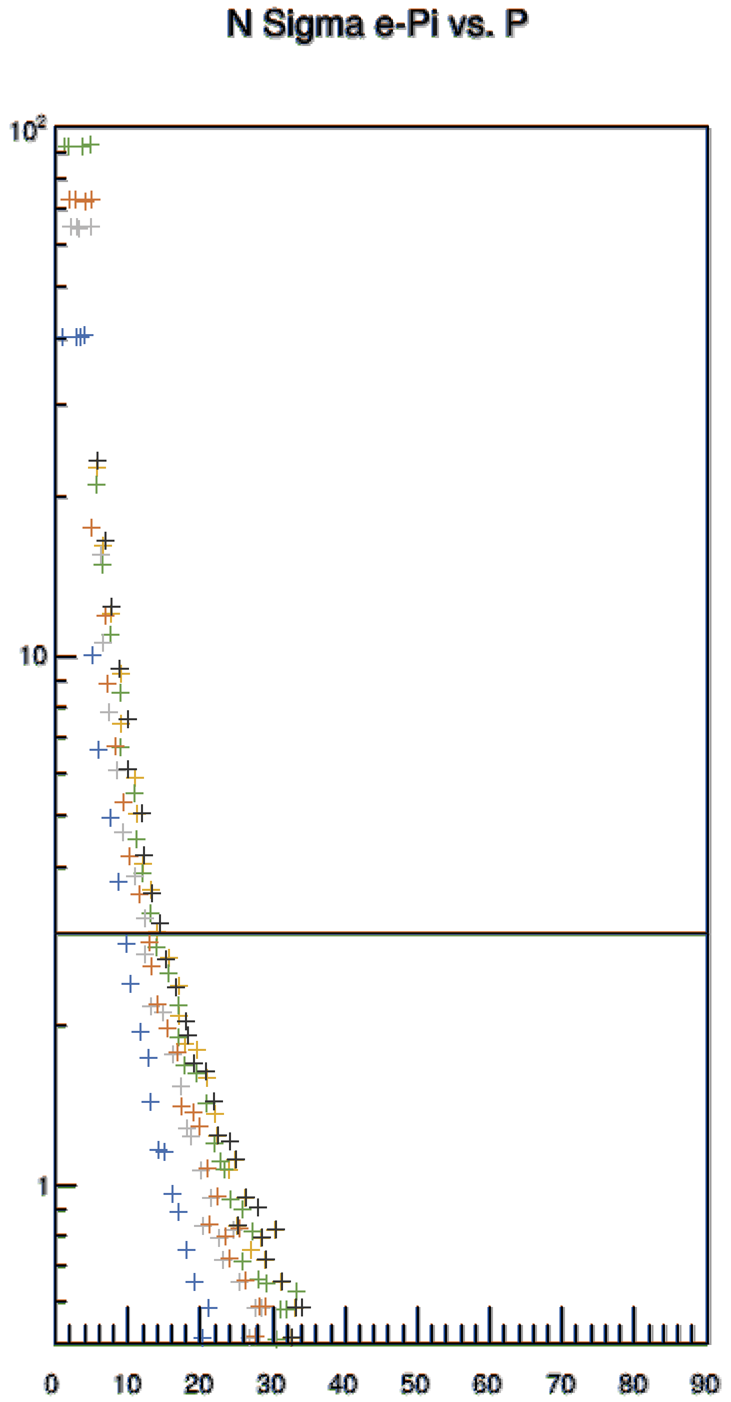
Tracking angular resolution will contribute to σ_θ

Tracking σ_θ calculated for Pi, Ka, Pr, e at various momenta, no large dependence on momentum or species at momenta of relevance (near saturation limit)
σ_θ calculated here for Pions at 30 GeV

Variations in σ_θ due to species and momentum can be explored in the future


N Sigma Pi-Ka vs. P
Blue: 20 mrad tracking error
Grey: 10 mrad tracking error
Orange: 8 mrad tracking error
Green: 4 mrad tracking error
Gold: 2 mrad tracking error
Black: 1 mrad tracking error
10^2
10
1
0
10
20
30
40
50
60
70
80
90


N Sigma Ka-Pr vs. P
Realistic EIC detector situation:
Npe values according to test beam,
3mm hex pads, magnetic field,
emission smears included
10^2
10
1
0
10
20
30
40
50
60
70
80
90


N Sigma e-Pi vs. P
10^2
10
1
0
10
20
30
40
50
60
70
80
90

Tracking Error Summary Table

Tracking Error (mrad)	Pi-K 3 sigma threshold (GeV)	K-Pr 3 sigma threshold (GeV)	e-Pi 3 sigma threshold (GeV)
20	30	52	10
10	38	65	12
8	42	68	13
4	46	78	14
2	49.5	80	15
1	50	81	15

According to this parameterization, tracking is leading error contribution if worse than ~7 mrad, becomes negligible resolution factor around 2 mrad. Between 2 and 7mrad , more detailed investigation is required.

To-do

- Investigate other gases and variations in pressure. Find an optimal index of refraction for EIC physics and see if we can hit it
- Learn from physics WG what processes require what capabilities- other than “we need high momentum!” what is high?
- Explore backgrounds that produce stray light
- Implement some polar angle and momentum resolution dependence
- Clean up the code so others can use it if they want
- Other suggestions?

Conclusions

Feedback to trackers

- Coding mistakes must not be too bad, reproduce dRICH + test beam results reasonably well
- Better than 2mrad for track direction inside radiator looks ok
- Worse than 4 mrad looks questionable
- Worse than 8 mrad… very bad
- Note: Sandwiching RICH with trackers on both sides should produce better than 2mrad, even with inexpensive tracking technology
- Note 2: At some point, Tracking can do more harm than good. At that point it’s best to stop seeding rings with tracking and start finding them organically. Finding this point can be a future to-do.
- Although PID performance at high momentum is similar to dRICH, dRICH has broader momentum range.